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Dated 21 November 2003

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1. Your reference	R071787PGB		
2. Patent application number *(The Patent Office will fill in this part)*	0225392.0		
3. Full name, address and postcode of the or of each applicant *(underline all surnames)*	Delphi Technologies, Inc PO Box 5052, Troy Michigan 48007 United States of America		
Patents ADP number *(if you know it)*	7588320001		
If the applicant is a corporate body, give the country/state of its incorporation	Delaware, United States of America		
4. Title of the invention	FUEL SYSTEM		
5. Name of your agent *(if you have one)* "Address for service" in the United Kingdom to which all correspondence should be sent *(including the postcode)* 21/1/03	~~Marks & Clerk Alpha Tower Suffolk Street Queensway Birmingham B1 1TT United Kingdom~~ David Keltie Associates Fleet Place House 2 Fleet Place London EC4M 7ET		
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11. I/We request the grant of a patent on the basis of this application.

Signature

Date 31 OCT 2002

12. Name and daytime telephone number of person to contact in the United Kingdom — Joanne Pople 0121 643 5881

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FUEL SYSTEM

This invention relates to a fuel system for use in delivering fuel to a cylinder of an associated compression ignition internal combustion engine of the type provided with an after treatment device for the purpose of emission level control. The invention also relates to a method of delivering fuel to an engine.

Known fuel systems commonly include a fuel pump having one or more cam driven plungers arranged to pressurise fuel within a pumping chamber for delivery to the injectors of the associated engine. In a unit pump/injector scheme, a single plunger is driven to pressurise fuel within a pumping chamber, from where high pressure fuel is delivered to the delivery chamber of an injector located within a housing common to the pump elements. Alternatively, the pump and the injector may communicate through a separate high pressure fuel line interconnecting the pumping chamber with an injector delivery chamber.

It is a recent development in diesel engine technology to provide the engine with an after treatment device for the purpose of improving exhaust emission levels. For regeneration purposes, such devices periodically require an injection of fuel to the engine sometime after a main injection event (referred to as "late post injection"). Typically, such late post injection of fuel may be required several times for any one tank of fuel used.

It is an object of the present invention to provide a fuel system which enables this to be achieved.

According to a first aspect of the invention there is provided a fuel system for use in an internal combustion engine, the fuel system comprising;

a fuel pump having a pumping cycle during which fuel is pressurised to a high level within a pumping chamber for delivery to an injector, whereby the injector is arranged to provide a primary fuel injection event, and a secondary fuel injection event within the same pumping cycle, in use,

the injector including a valve needle which is engageable with a valve needle seating to control fuel delivery through an injector and injection valve control means for controlling movement of the valve needle so as to control the primary and secondary fuel injection events,

the fuel system further comprising an accumulator volume for storing high pressure fuel for delivering the secondary fuel injection quantity, and additional valve means for controlling the supply of fuel stored within the accumulator volume to the injector for the secondary injection event.

For the purpose of this specification, the phrase "secondary injection event" is not limited to an event which occurs later than a "primary injection event" in a pumping cycle, and the secondary injection event may equally occur before the primary injection event.

The fuel system is particularly suitable for use in an engine provided with an after treatment device for reducing emission levels. In such circumstances, the primary injection event takes the form of a main fuel injection event, during which a main fuel injection quantity is delivered, and the secondary injection event takes the form of a late post injection event, during which a late post fuel injection quantity is delivered, whereby the late post injection of fuel occurs after the main injection of fuel in the pumping cycle.

The after treatment device associated with the engine may be a nitrogen oxide absorber type device (a NOx absorber device), in which case the additional valve means is preferably arranged to deliver a late post fuel injection quantity which may be approximately the same as the main fuel injection quantity.

Alternatively, if the after treatment device is of the diesel particulate filter (DPF) type, the additional valve means is preferably arranged to deliver a late post fuel injection quantity which may be approximately between 5 and 20% of the main fuel injection quantity.

In one embodiment, the injection control valve means and the additional valve means may be arranged to provide a sequence of typically around 3 to 5 consecutive main fuel injection events, each of which is accompanied by a late post fuel injection event. Preferably, this sequence may be provided once for each tank of fuel used.

In another embodiment, the injection control valve means and the additional valve means may be arranged to provide a periodic distribution of late post fuel injection events between main fuel injection events. The late post fuel injection events may typically be provided between 3 and 5 times for each tank of fuel used by the engine. The number of late post fuel injection events will be selected according to the requirements of the engine/after treatment device specifications.

The additional valve means may conveniently take the form of an electronically operable valve, preferably an electromagnetically operable valve. In one embodiment, the additional valve means includes an electromagnetically operable actuator for switching the additional valve means between open and closed states, wherein the actuator is common to the injection control valve

means.

In an alternative embodiment, the additional valve means may take the form of an hydraulically operable valve. The hydraulically operable valve may include a valve member which is movable between open and closed states in response to a fuel pressure difference across the valve member, or control surfaces of the valve member, whereby when the valve member is in the open state fuel from the accumulator volume is able to flow from the accumulator, through a return passage, into the high pressure fuel line for the purpose of administering the late post injection of fuel.

Preferably, the valve member is biased towards a closed state by means of a valve spring housed within a spring chamber. The spring chamber may communicate with a low pressure drain, or the accumulator volume or the high pressure line, with the spring rate and dimensions of the valve member being selected accordingly to ensure the valve member is urged into the open state when the required pressure difference exists across the valve member or control surfaces thereof.

In another embodiment, the additional valve may also include at least a first non-return valve arranged in a primary supply passage for controlling the flow of high pressure fuel from the high pressure supply line to the accumulator volume.

Conveniently, the fuel system may include a drive arrangement for the pumping plunger. Preferably, the drive arrangement takes the form of a cam drive arrangement including a cam having a surface with one or more cam lobes. Preferably, the cam drive arrangement includes a roller and a drive member, whereby the roller cooperates with the cam surface to impart

movement to the drive member, thereby to drive the pumping plunger to perform a pumping stroke during which the plunger moves to reduce the volume of the pumping chamber.

The invention is not limited to use in administering a late post injection of fuel for the purpose of regenerating an after treatment device associated with the engine, but equally may be used to provide a pilot injection of fuel just before or just after a main fuel injection of fuel, or may be used to shape the injection rate characteristics.

For example, the injection control valve means and the additional valve may be arranged to provide the primary injection event at a primary fuel injection rate, and the secondary injection event at a secondary fuel injection rate which is greater than the primary fuel injection rate (i.e. a so-called "boot-shaped" injection).

According to a second aspect of the invention there is provided a method of delivering fuel to an internal combustion engine provided with an after treatment device for reducing emission levels, the method comprising;

driving a pumping plunger to perform a pumping stroke of a pumping cycle, thereby to pressurise fuel within the pumping chamber to a high level, following which the pumping plunger performs a return stroke of the pumping cycle,

delivering high pressure fuel to an injector associated with the engine through a high pressure line,

controlling an injection control valve means to move between an open state to commence a main fuel injection event and a closed state to terminate the main fuel injection event, during which main fuel injection event a main fuel injection quantity is delivered to the engine, and

moving the injection control valve means from the closed state to the open state to permit a late post fuel injection quantity to be delivered to the engine, within the pumping cycle and a period of time after the main fuel injection event, for the purpose of regeneration of the after treatment device.

In one embodiment, the method is achieved by appropriate shaping of the cam surface to ensure that the main fuel injection event is terminated prior to completion of the pumping stroke (i.e. just prior to full plunger lift), just before the plunger rides over the peak of the cam lobe. Thus, the cam may be shaped such that there is a sufficient period at the end of the pumping stroke (just prior to full plunger lift) to charge the high pressure volume of the pumping chamber (and any interconnecting high pressure fuel passage(s)) with sufficient fuel as is required for the late post fuel injection event. This aspect of the invention avoids the need for the additional valve and the accumulator volume (and possibly a non-return valve in the high pressure line), and instead relies on trapped fuel within the high pressure line and interconnecting passages being delivered for the late post injection event.

The late post injection event may be administered after the completion of the pumping stroke, either just after full plunger lift during a "top dwell" period between the pumping stroke and the return stroke, just after the plunger commences the return stroke or some time after the plunger commences the return stroke (up to an engine position of, for example, 90 degrees after top-dead-centre).

Preferably, the step of providing the late post fuel injection quantity may be performed for up to 5% of main fuel injections.

In one embodiment, the method includes the step of providing a sequence of around 3 to 5 consecutive main fuel injection events, each of which is accompanied by a late post fuel injection event.

More preferably, said sequence is provided once for each tank of fuel used by the engine.

In another embodiment, the method may include the step of providing a periodic distribution of late post injection events between main fuel injection events.

Preferably, the late post injection events are provided several times for each tank of fuel used by the engine.

It will be appreciated that preferred and/or optional features of the first aspect of the invention are equally applicable to the second aspect of the invention.

The invention will further be described, by way of example, with reference to the accompanying drawings in which:

Figure 1 is a schematic diagram to illustrate a fuel system in accordance with a first aspect of the invention,

Figures 2 to 5 show alternative designs for a hydraulically operable late post injection control valve for use in the system of Figure 1, and

Figure 6 is a schematic diagram to illustrate an alternative fuelling method in accordance with a second aspect of the invention.

The fuel system illustrated in Figure 1 is suitable for use in fuelling an engine provided with an after treatment device for the purpose of regulating emission levels. Such devices may be of the NOx absorber type, or may be of the diesel particulate filter (DPF) type, both of which are known in the art. For the purpose of regenerating such devices, it is necessary to inject a quantity of fuel into the engine some time after a main fuel injection event, commonly referred to as "late post fuel injection". Such late post fuel injection is typically required for up to 5% of main injection events.

The fuel system includes a unit fuel pump 10, the outlet 11 of which communicates through a high pressure fuel line 12 with an inlet 13 of an electronically controlled fuel injector 14. The pump 10 and the injector 14 are both controlled electronically by a control unit (not shown) which receives signals from a plurality of sensors monitoring, for example, engine speed, position and temperature. The signals supplied to the control unit by the sensors are used in controlling the operation of the fuel system to appropriately control the pressure of fuel supplied to the injector 14 and the timing at which injection of fuel to a cylinder of an associated engine takes place, as described in further detail below.

The fuel injector comprises a valve needle 16 which is slideable within a bore formed in a nozzle body 18. The needle 16 includes angled thrust surfaces 16a orientated such that the application of fuel under high pressure from the high pressure fuel line 12 applies a force to the valve needle 16 urging the valve needle 18 out of engagement with a valve needle seating to permit fuel injection into the engine.

The injector is preferably of the type in which fuel is supplied to a control chamber (not shown) from the high pressure fuel line 12, through an injector supply passage (not shown). The control chamber communicates continuously with the injector supply passage through a restriction. Fuel pressure within the control chamber is controlled by means of injection control valve means, typically in the form of an electromagnetically operable injection control valve, which is arranged to control communication between the control chamber and a low pressure drain. By controlling the injection control valve to move between open and closed states, valve needle movement towards and away from the valve needle seating is controlled to provide the required fuel injection characteristics.

The unit pump 10 is of a known type, including a pump housing 20 defining a bore (not shown) within which a pumping plunger 22 is reciprocable under the action of a cam drive arrangement mounted upon an engine driven shaft and arranged to act against a return spring 24. The plunger bore defines, together with an end surface of the plunger, a pumping chamber (not shown) which communicates with the high pressure fuel line 12 through a non-return delivery valve 32 in a known manner. The non-return valve 32 is urged into an open position in which the pump outlet 11 communicates with the injector inlet 13, when fuel pressure within the pumping chamber is increased beyond a predetermined amount.

The cam drive arrangement includes a cam 26 having a cam surface 28 with one or more cam lobes, the cam surface 28 cooperating with a roller 30 of the cam drive arrangement to cause reciprocating movement of the plunger 22 within its bore through a drive member 31, typically in the form of a tappet or a shoe. In use, as the roller 30 rides over the surface of the cam 26, the plunger 22 performs a pumping cycle including a pumping stroke during which the

plunger is driven inwardly within its bore to reduce the volume of the pumping chamber, and a return stroke during which the plunger is urged outwardly from its bore under the action of the return spring 24 to increase the volume of the pumping chamber. When the plunger adopts its innermost position within its bore, and the volume of the pumping chamber is at a minimum, the plunger is said to be at "full plunger lift".

For some cam profiles, the plunger may also experience what is commonly referred to as "top dwell", where the plunger remains, or "dwells", on the lobe of the cam surface for a period of time following the pumping stroke but before the return stroke commences.

Downstream of the non-return valve 32, the high pressure line 12 communicates with a reservoir or accumulator volume 34 for high pressure fuel through a flow path 36 provided with an additional valve means in the form of a late post injection control valve 38. The late post injection control valve 38 is preferably provided with an electromagnetic actuator for switching the valve between an open state, in which the high pressure line 12 communicates with the accumulator volume 34, and a closed state in which communication between the line 12 and the volume 34 is broken. If desired, a pressure transducer 35 may be provided for measuring the pressure of fuel within the accumulator volume 34, and an output signal from the pressure transducer 35 may be fed back to the control unit for the purpose of controlling valve operation.

Fuel pumps of the type shown in Figure 1 are generally known, and are operable to control the timing of commencement of fuel pressurisation within the pumping chamber under the control of a pressure control valve (not

shown). The description of such a fuel pump may be found in the Applicants co-pending European patent application EP 0957261 A2.

By way of example, Figure 2 shows an electromagnetically actuable valve 138 which may be used to control the flow of fuel between the accumulator volume 34 and the high pressure fuel line 12. The late post injection control valve 138 includes a pressure balanced on-off valve member 138a which is movable between an open state, in which an enlarged portion 138b thereof is moved away from a valve seating to permit communication between the accumulator 34 and the high pressure fuel line 12, and a closed state in which the enlarged portion 138b is seated to close communication. The control valve 138 includes an associated electromagnetic actuator (not shown) which is energisable to switch the valve member 138a between its open and closed positions in response to signals received from the control unit, which signals are generated in response to the output from the pressure transducer 35.

As an alternative, or in addition, the control signals for the control valve 138 may be generated in response to other engine fuelling requirements.

As the drive shaft rotates in use, the cam drive arrangement permits outward movement of the plunger under the action of the return spring 24 (the return stroke), during which fuel at relatively low pressure is drawn from a fuel reservoir through the open pressure control valve to the pumping chamber. Initially, the injection control valve of the injector 14 is de-energised and is in its closed state to ensure fuel pressure within the control chamber is sufficiently high to seat the valve needle 16, thus ensuring injection does not take place.

The movement of the cam drive arrangement results, subsequently, in the plunger reaching its outermost position and commencing inward movement

(the pumping stroke), during which the volume of the pumping chamber is reduced. Whilst the pressure control valve of the pump remains de-energized, inward movement of the pumping plunger simply displaces fuel back to the low pressure drain reservoir, and thus does not result in pressurization of the high pressure fuel line 12. When it is determined that pressurization of the fuel line 12 should commence, a signal is applied by the control unit to the pressure control valve to cause it to close, thereby breaking communication between pumping chamber and the low pressure drain. Continued inward movement of the pumping plunger as the roller 30 rides over the cam surface 28 therefore results in pressurization of the fuel within the pumping chamber, and a point will be reached at which the delivery valve of the pump is caused to open to permit fuel flow into the high pressure fuel line 12.

As a result of the pressurization of the fuel within the high pressure fuel line 12, the fuel pressure applied to the injector 14 increases, but as the injection control valve of the injector 14 is closed, the fuel pressure within the control chamber and that applied to the thrust surfaces 16a of the valve needle 16 are substantially equal thus ensuring that the valve needle 16 remains in engagement with its seating.

Initially during the pumping stroke, the late post injection control valve 38 in the flow passage 36 is in its open state to permit pressurised fuel in the line 12 to flow into the accumulator volume 34. When fuel pressure within the accumulator volume 34 reaches the required level for late post injection, as measured by the pressure transducer 35, the late post injection control valve 38 is closed by switching the electromagnetic actuator to terminate flow into the volume 34, as described further below.

Alternatively, the late post injection control valve may be closed in response to a prediction in compression based on the amount of plunger movement and system volume.

When it is required to commence a primary (main) injection of fuel, for which a main fuel injection quantity is injected into the engine, the electromagnetic actuator of the injection control valve is energised causing the injection control valve to open. Fuel is therefore able to flow from the control chamber to the low pressure drain such that fuel pressure within the control chamber falls, thereby reducing the magnitude of the force urging the valve needle towards its seating and permitting the valve needle 16 to lift under the action of the fuel acting upon the thrust surfaces16a. Such movement of the valve needle 16 permits fuel to flow past the seating to one or more injector outlets, and through the outlet(s) to be injected to the engine cylinder.

When the desired quantity of fuel has been delivered to the engine during the main injection event, the injection control valve is closed to increase fuel pressure within the control chamber. The magnitude of the force urging the valve needle 16 towards its seating is therefore increased, until a point is reached beyond which the valve needle 16 returns into engagement with its seating, thus terminating the supply of fuel to the engine cylinder. It will be apparent from the description hereinbefore that the operation of the injection control valve of the injector controls the timing at which fuel injection takes place.

For the purpose of regenerating the after treatment device associated with the engine, it is necessary to provide a secondary injection of fuel late in the pumping cycle, as described previously. Preferably, this is required when engine position is between 20° and 180° after the main injection event, and

more preferably when it is around 30° after the main injection event. The desired injection timing range and the peak injection pressure are determined by appropriate shaping of the cam profile, but this can present a problem in known fuel systems as the cam profile shape limits the fuelling period. The requirement for a late post injection of fuel after the main injection cannot therefore be accommodated in known schemes.

The present invention overcomes this, however, by providing the accumulator volume 34 and the additional late post injection control valve 38. The cam surface 28 is shaped such that, at the end of the main injection event when the injection control valve is moved to its closed state to reseat the valve needle 16, the plunger is only part way through its pumping stroke, and so pressurisation of fuel within the pumping chamber continues after the main fuel injection event has terminated. High pressure fuel thus continues to flow into the high pressure line 12, and hence into the accumulator volume 34, until such time as the late post injection control valve 38 is closed to trap high pressure fuel within the volume 34. Switching of the late post injection control valve 38 into its closed state is controlled by means of the electromagnetic actuator under the control of the control unit, which generates control signals for the actuator in response to the output from the pressure transducer 35, for example, to indicate that fuel pressure within the accumulator volume 34 has reached the required level.

When it is desired to inject the late post fuel injection quantity, the late post injection control valve 38 is actuated to its open state, therefore permitting a further flow of high pressure fuel to the high pressure line 12 and, hence to the injector 14. At substantially the same time the injection control valve is energised once more to cause the valve needle 16 to lift, thereby to permit the late post injection of fuel into the engine. The injector 14 is typically operated

in accordance with a so-called "pressure-time" delivery regime whereby, for a given delivery pressure, the valve needle 16 is held open for an appropriate period of time to give the required late post injection delivery quantity.

Inward movement of the pumping plunger continues until the plunger reaches its innermost position within its bore and the volume of the pumping chamber is at a minimum, after which the plunger may dwell and then commence outward movement under the action of the spring 24 acting in combination with any residual fuel pressure within the pumping chamber. The late post injection of fuel may preferably be provided when the plunger is close to or just after full plunger lift. This includes, for example, providing the late post injection of fuel when the plunger is performing its return stroke. When it is desired to terminate the late post injection of fuel, both the late post injection control valve 38 and the injection control valve are moved to their closed positions.

It will be appreciated that, as the plunger commences its return stroke and fuel pressure within the pumping chamber is reduced, the non-return valve 32 is caused to close under the force of high pressure fuel in the line 12. Thus, flow of high pressure fuel from the accumulator volume 34, back through the line 12 to the pump is prevented, even if the late post injection control valve 38 is opened.

The fuel system in Figure 1 may be operated in an alternative way, by controlling the late post injection control valve 38 such that the accumulator volume 34 is filled gradually over a series of pumping cycles, rather than by filling the volume 34 completely during one cycle before the main injection takes place.

As an alternative scheme to that shown in Figure 2, the late post injection control valve 38 need not be provided with an actuator, but may be hydraulically operable in dependence upon fuel pressure within the accumulator volume 34 and the passage 36 (and hence the high pressure line 12). Examples of alternative hydraulically operable late post injection control valves 38 are shown in Figures 3 to 5.

The late post injection control valve 238 of Figure 3 includes a valve member 238a which is biased closed by means of a valve spring 240 housed within a spring chamber 242 connected to low pressure. The control valve 238 also includes first and second non-return valves 244, 246 arranged in primary and return flow passages 248, 250 respectively. The valve member 238a is hydraulically operable between open and closed states in response to the fuel pressure difference across the valve member 238a i.e. between fuel pressure within the accumulator volume 34 and fuel pressure within the spring chamber 242. When fuel pressure within the accumulator volume 34 is relatively low, the first non-return valve 244 is forced open due to high pressure fuel within the line 12 and the accumulator 34 is thus filled with high pressure fuel. As fuel pressure within the accumulator 34, and hence within the primary flow passage 248, increases, a point will be reached at which the pressure difference across the valve member 238a exceeds a predetermined amount, governed by the biasing force of the spring 240 and low pressure fuel within the chamber 242. At this point the valve member 238a is urged open and high pressure fuel is able to flow through the return flow passage 250, urging the second non-return valve 246 open and permitting high pressure fuel from the accumulator 34 to flow into the line 12, ready for the late post injection of fuel.

It will be appreciated that other control surfaces of the valve member 238a, for example the angled surface 238b) will also experience a force due to fuel

pressure, and that the phrase "fuel pressure difference across the valve member" is intended to mean the difference between fuel pressure acting to move the valve member in a first direction and fuel pressure acting to move the valve member in a second, opposite direction.

As an alternative to Figure 3 (not shown), the non-return valves 244, 246 and the passage 250 may be omitted so that only a single valve member 238a controls communication between the accumulator 34 and the high pressure line 12 which, again, is movable in response to the fuel pressure difference across it. In a further alternative embodiment, the non-return valve 246 is omitted but the passage 250 is included.

As a further alternative to Figure 3 (also not shown), the chamber 242 housing the spring 240 may communicate with the high pressure line 12, instead of low pressure, with the spring rate and the dimensions of the valve member 238a are adjusted accordingly.

Figure 4 shows an alternative hydraulically operable valve 338 including a pressure balanced switching valve member 338a. The valve member 338a is movable between open and closed states in response to the fuel pressure difference across the valve member 338a. A non-return valve 344 is provided to control the flow into the accumulator volume 34 from the high pressure line 12. When the non-return valve 344 is urged closed due to increased pressure within the accumulator volume 34, and the valve member 338a is urged open, a return flow of fuel is permitted through a return flow passage 346, past the open valve member 338a, and back to the high pressure line 12, ready for the next late post injection event.

As in Figure 3, the chamber 342 for the spring 340 is shown in communication with low pressure, but alternatively the spring rate and the valve 348a may be dimensioned such that the spring chamber communicates with the high pressure line 12 instead.

Figure 5 is a still further alternative design for an hydraulically operable control valve 438, in which no no-return valves are provided. The valve 438 includes a valve member 438a having an enlarged, seatable portion 438b, which is movable in response to the difference fuel pressure across the valve 438a. A first end of the valve member 438a experiences a force due to a spring 440 in a spring chamber 442 (along with a force due to low fuel pressure in the chamber 442) and the opposite end of the valve member 438a experiences a force due to high pressure fuel in the chamber 446. When the force due to fuel pressure within the chamber 446 (i.e. within the high pressure line 12) is sufficient to overcome the force acting on the first end of the valve member 438a (acting in combination with fuel pressure acting on the enlarged portion 438b), the valve is urged closed to prevent flow between the line 12 and the volume 34.

Again, in Figure 5 the chamber 442 is shown as being in communication with low pressure, but alternatively it may communicate with the accumulator volume 34 with the spring force and the valve member 438a dimensions selected accordingly to cause the valve 438 to open when the required pressure is achieved in the accumulator volume 34.

In a further alternative scheme (not shown) to that described with reference to Figures 1 to 5, the late post injection valve 38 and the injection control valve need not be provided with separate actuators, but may be configured to share a common actuator which is operable under the control of the control unit to control the respective timing of main and late post injection.

In practice, it may only be necessary to provide the injector associated with one cylinder of the engine with the late post injection control valve 38 and the accumulator volume 34 for the purpose of administering the late post injection of fuel.

The fuel system is not limited to use in administering a late post injection of fuel for the purpose of regenerating an after treatment device associated with the engine, but instead may be used to provide a pilot injection of fuel just before or just after a main fuel injection of fuel. For example, the invention may be used to provide a close-coupled post injection, shortly after the main injection of fuel.

Alternatively, the invention may be used to shape the injection characteristic of a main injection event, for example by providing a primary fuel injection event at a primary fuel injection rate, and a secondary fuel injection event at a secondary fuel injection rate. If the secondary fuel injection event is greater than the primary fuel injection rate, the injection event has a so-called "boot-shaped" injection characteristic. In this embodiment, the primary and secondary injection events are sequential (i.e. back to back) and effectively form a single injection event having a first stage low injection rate and a second stage higher injection rate.

Referring to Figure 6, in a further alternative embodiment the late post injection control valve 38 and the accumulator volume 34 may be deleted. Instead, the injection control valve alone is operable to provide both the main injection of fuel and the late post injection of fuel. This is achieved by shaping the cam profile to ensure the plunger performs the remainder of its pumping stroke after the main injection event is terminated. Once the main injection

event has been terminated by closing the injection control valve, fuel pressurisation within the pumping chamber continues until the end of the pumping stroke. During the remainder of the pumping stroke, the injection control valve is re-opened to commence the late post injection of fuel and is closed when the desired quantity of fuel has been injected.

Alternatively, the injection control valve may be re-opened after full plunger lift to provide the late post injection of fuel, providing that enough pressurised fuel remains trapped in the high pressure line 12 after the main injection to provide the required late post injection delivery quantity. For example, the cam surface 28 may be shaped such that the plunger remains at "top-dwell" for a period of time between the end of the pumping stroke and the start of the return stroke, and the late post injection may be administered during this period. Alternatively, the late post injection may be administered at the start of the return stroke, or well into the return stroke when the plunger is some way down the trailing edge of the cam lobe.

The embodiment of the invention described with reference to Figure 6 is particularly suitable for applications where the required late post injection fuel quantity is relatively small, for example around 10% of the main fuel injection quantity. Such late post injection fuelling amounts are particularly suitable for use with DPF type after treatment devices.

For applications where a relatively large late post injection fuel quantity is required, for example volumes approaching the main fuel injection quantity, it may be more appropriate to use the embodiments shown in Figures 1 to 5. In particular, this embodiment is suitable for use in engines provided with an NOx absorber type device.

It will be appreciated that the fuel system in accordance with the invention may include a fuel pump in which the quantity of fuel supplied to the pumping chamber is metered to permit control of the fuel injection pressure, rather than by means of a pressure control (spill) valve.

As an alternative to any of the embodiments shown in Figure 1 to 5, the non return valve 32 may be removed due to the provision of the additional valve 38.

CLAIMS

1. A fuel system for use in an internal combustion engine, the fuel system comprising;

a fuel pump having a pumping cycle during which fuel is pressurised to a high level within a pumping chamber for delivery to an injector, whereby the injector is arranged to provide a primary fuel injection event, and a secondary fuel injection event within the same pumping cycle, in use,

the injector including a valve needle which is engageable with a valve needle seating to control fuel delivery through an injector and injection valve control means for controlling movement of the valve needle so as to control the primary and secondary fuel injection events,

the fuel system further comprising an accumulator volume for storing high pressure fuel for delivering the secondary fuel injection quantity, and additional valve means for controlling the supply of fuel stored within the accumulator volume to the injector for the secondary injection event.

2. A fuel system as claimed in Claim 1, whereby the primary injection event takes the form of a main fuel injection event, during which a main fuel injection quantity is delivered, and the secondary injection event takes the form of a late post injection event, during which a late post fuel injection quantity is delivered, whereby the late post injection of fuel occurs after the main injection of fuel in the pumping cycle.

3. A fuel system as claimed in Claim 2, including an after treatment device.

4. A fuel system as claimed in Claim 2 or Claim 3, wherein the additional valve means is arranged to deliver a late post fuel injection quantity which is approximately the same as the main fuel injection quantity.

5. A fuel system as claimed in Claim 2 or Claim 3, wherein the additional valve means is arranged to deliver a late post fuel injection quantity of approximately between 5 and 20% of the main fuel injection quantity.

6. A fuel system as claimed in any one of Claims 2 to 5, including injection control valve means and additional valve means arranged to provide a sequence of between 3 and 5 consecutive main fuel injection events, each of which is accompanied by a late post fuel injection event.

7. A fuel system as claimed in any one of Claims 2 to 5, including injection control valve means and additional valve means arranged to provide a periodic distribution of late post fuel injection events between main fuel injection events.

8. A fuel system as claimed in any one of Claims 2 to 7, wherein the additional valve means take the form of an electromagnetically operable valve.

9. A fuel system as claimed in any one of Claims 2 to 7, wherein the additional valve means take the form of an hydraulically operable valve.

10. A fuel system as claimed in Claim 9, wherein the hydraulically operable valve includes a valve member which is movable between open and

closed states in response to a fuel pressure difference across the valve member, whereby when the valve member is in the open state fuel from the accumulator volume is able to flow from the accumulator, through a return passage, into the high pressure fuel line for the purpose of administering the late post injection of fuel.

11. A fuel system as claimed in Claim 10, wherein the valve member is biased towards a closed state by means of a valve spring housed within a spring chamber.

12. A fuel system as claimed in Claim 11, wherein the spring chamber communicates with low pressure.

13. A fuel system as claimed in Claim 11, wherein the spring chamber communicates with the accumulator volume.

14. A fuel system as claimed in Claim 11, wherein the spring chamber communicates with the high pressure line.

15. A fuel system as claimed in any one of Claims 9 to 14, wherein the additional valve further includes at least a first non-return valve, arranged in a primary supply passage, for controlling the flow of high pressure fuel from the high pressure supply line to the accumulator volume.

16. A fuel system as claimed in any one of Claims 1 to 15, wherein the injection control valve means and the additional valve are arranged to provide the primary injection event at a primary fuel injection rate, and the secondary injection event at a secondary fuel injection rate which is greater than the primary fuel injection rate.

17. A method of delivering fuel to an internal combustion engine provided with an after treatment device for reducing emission levels, the method comprising;

driving a pumping plunger to perform a pumping stroke of a pumping cycle, thereby to pressurise fuel within the pumping chamber to a high level, following which the pumping plunger performs a return stroke of the pumping cycle,

delivering high pressure fuel to an injector associated with the engine through a high pressure line,

controlling an injection control valve means to move between an open state to commence a main fuel injection event and a closed state to terminate the main fuel injection event, during which main fuel injection event a main fuel injection quantity is delivered to the engine, and.

moving the injection control valve means from the closed state to the open state to permit a late post fuel injection quantity to be delivered to the engine, within the pumping cycle and a period of time after the main fuel injection event, for the purpose of regeneration of the after treatment device.

18. A method as claimed in Claim 17, whereby the late post injection quantity is delivered after completion of the pumping stroke.

19. A method as claimed in Claim 18, whereby the late post injection quantity is delivered during a top dwell period between the pumping stroke and the return stroke of the plunger.

20. A method as claimed in any of one of Claims 17 to 19, including the step of providing a sequence of around 3 to 5 consecutive main fuel injection events, each of which is accompanied by a late post fuel injection event.

21. A method as claimed in Claim 20, whereby said sequence is provided once for each tank of fuel used by the engine.

22. A method as claimed in any one of Claims 17 to 19, including the step of providing a periodic distribution of late post injection events between main fuel injection events.

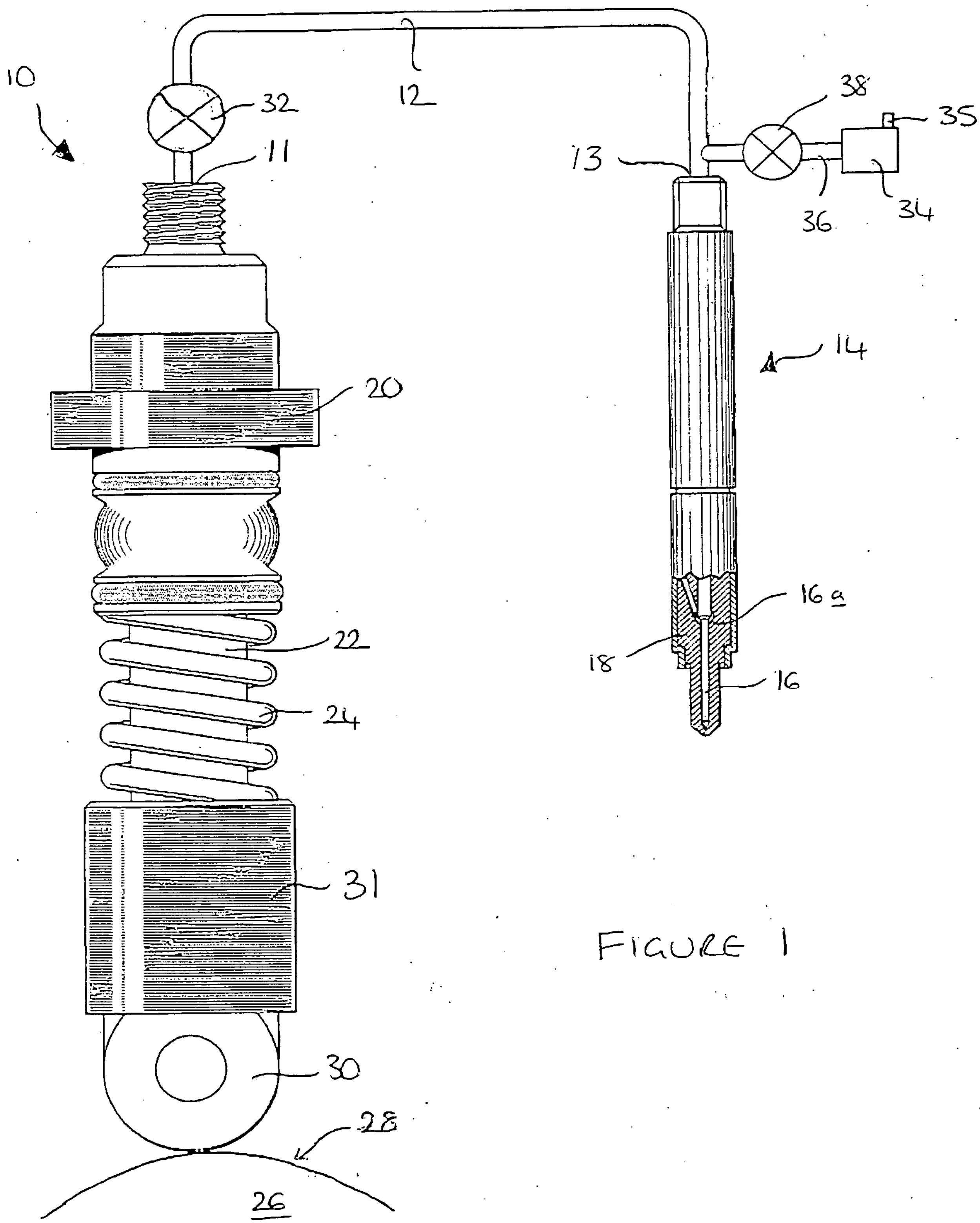

FIGURE 1

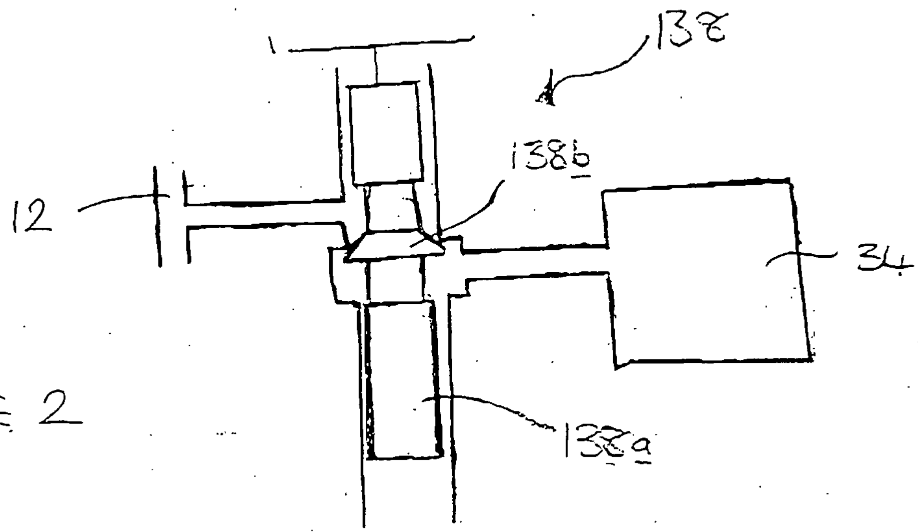

FIGURE 2

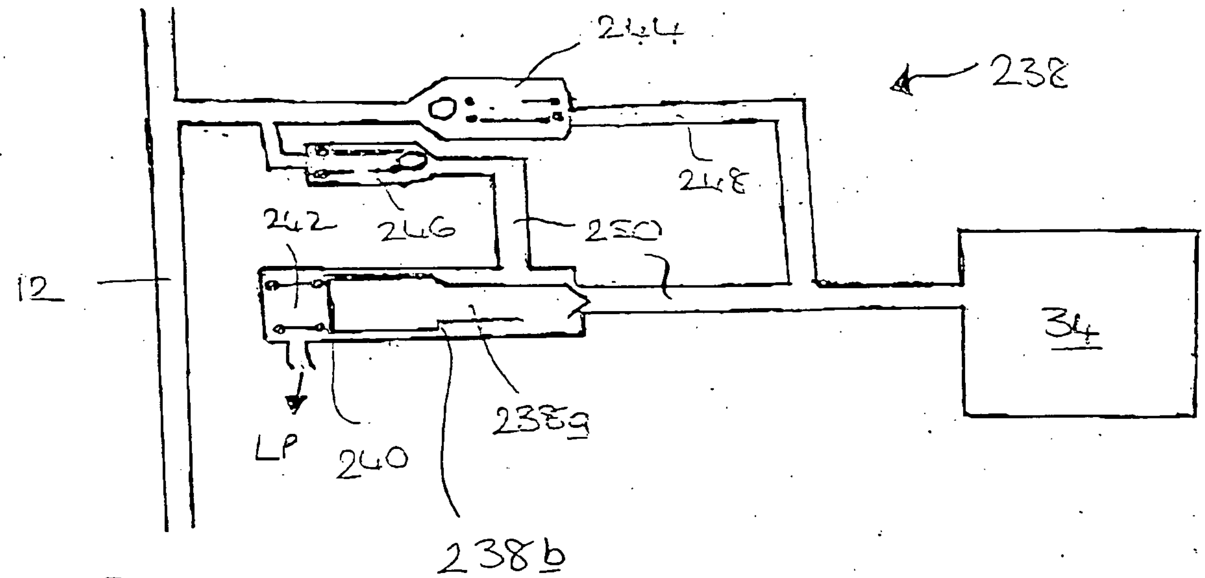

FIGURE 3

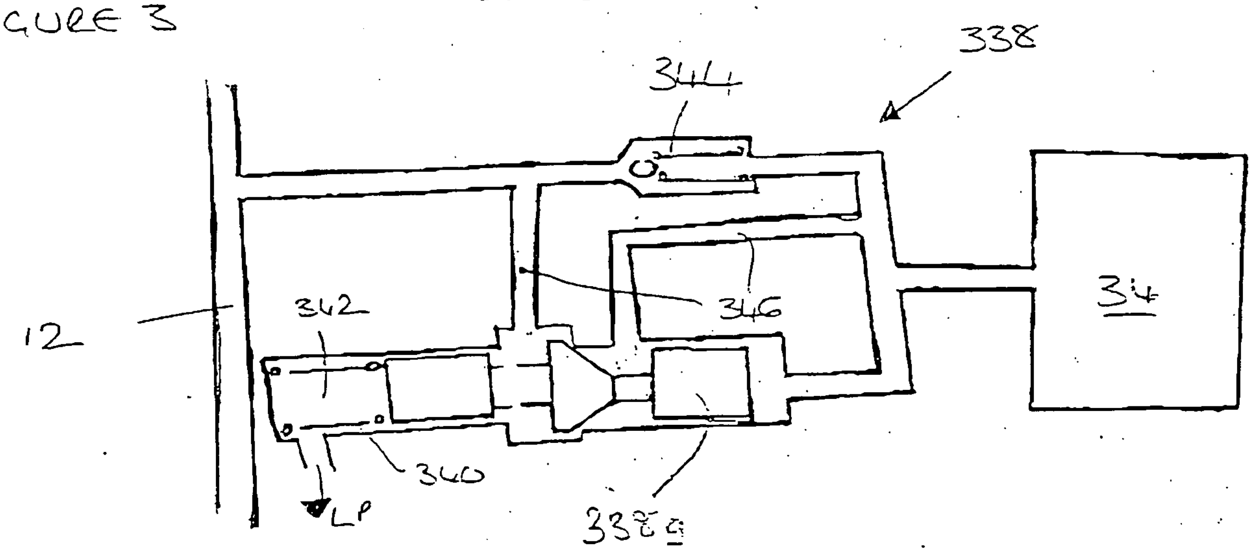

FIGURE 4

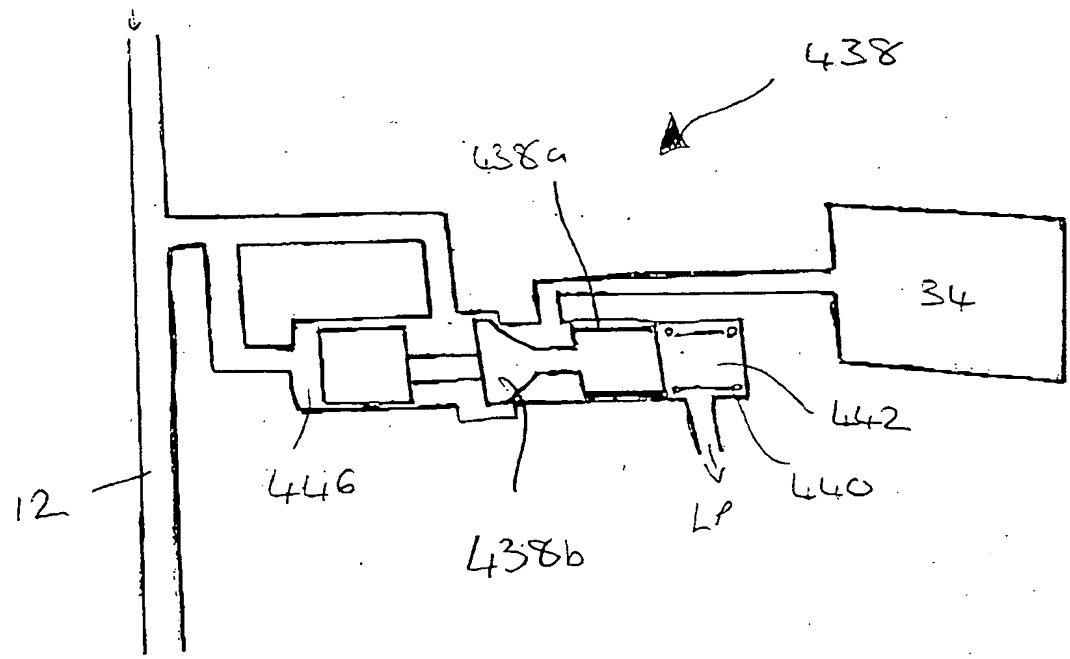

FIGURE 5

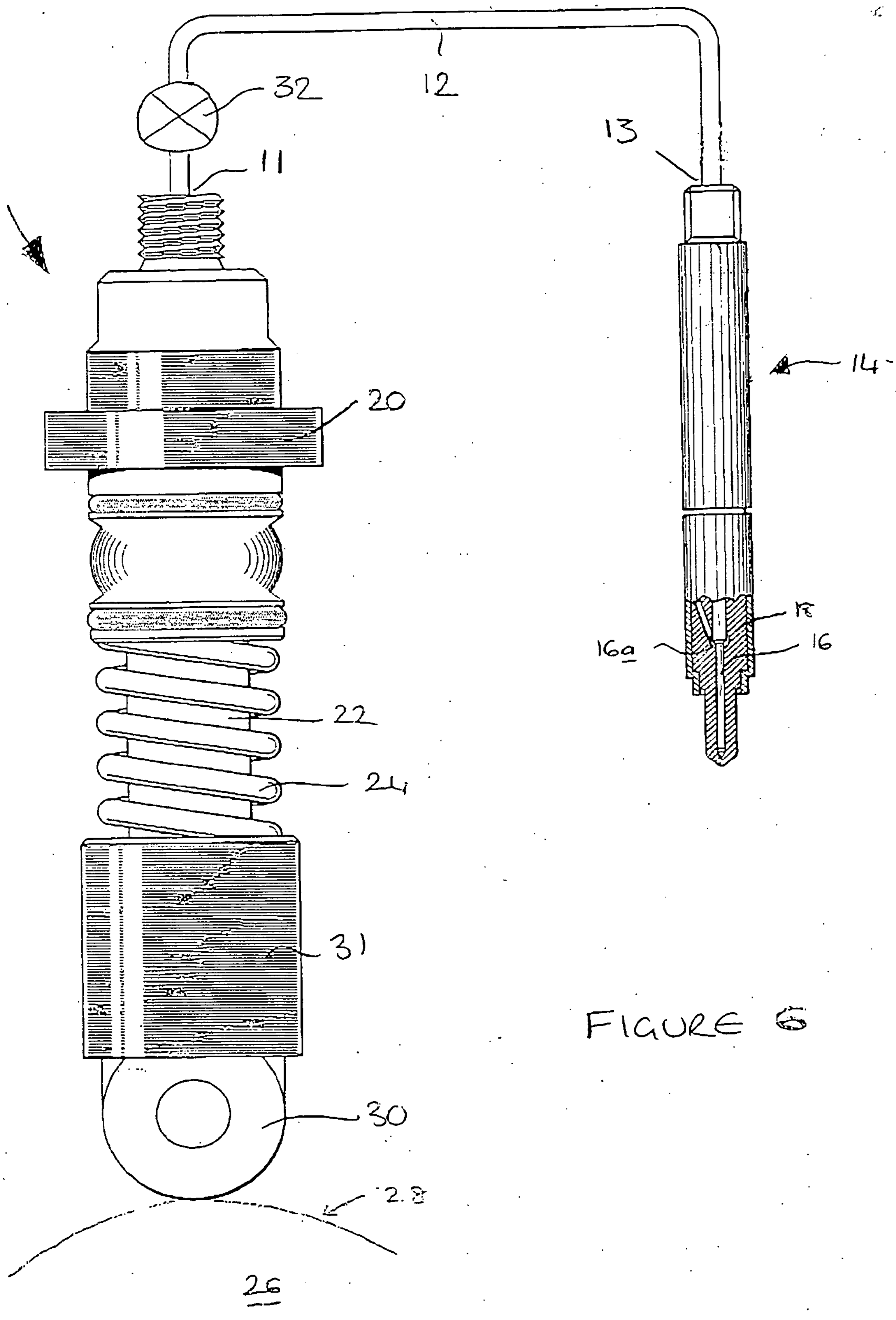

FIGURE 6